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General characteristics of the Thermoionic Vacuum Arc plasma

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The paper presents the main characteristics of an original deposition method for the synthesis of quality thin films using anodic arc plasma, called Thermionic Vacuum Arc - TVA. This plasma was observed for the first time about 30 years ago, but only in the last three-four years research started being focused on the coating capabilities of this plasma. The work undertaken until now has demonstrated a great potential of this plasma to become a powerful thin film deposition tool for a large range of applications.

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1. Introduction

The Thermionic Vacuum Arc (TVA) plasma was observed for the first time about 30 years ago in the Low Temperature Plasma Laboratory at our institute [1-18]. Since then, this arc plasma was studied as a new plasma source without particular interest on its coating capabilities. It is only three-four years ago when research on TVA plasma started being focused on deposition of thin films.

Due to its particularly high performance demonstrated within a short time interval, the TVA plasma has become an internationally appreciated coating technology. One of the most important current applications of the TVA is coating of the interior wall bricks of the tokamak to be built in Cadarache-France (ITER) with adherent and pure Be and W layers.

A brief introduction on the TVA method is presented in the following.

Generally, any deposition method contains the following steps:

Step 1: C*reation of the vapor phase species* which can be obtained by evaporation, sputtering, or laser ablation;

Step 2: *Transport of precursor species (ions, neutrals) from source to substrate* which takes place either with or without collisions; Step 3: *Nucleation of the species*.

In Thermionic Vacuum Arc plasma, the vapor-phase species are obtained by *evaporation*, the transport from the source to the substrate takes place *without collisions* and nucleation is obtained by both *neutral and ionic species*.

Thus, the TVA technique is a combination of evaporation by electron bombardment and anodic arc.

The basic principle of TVA is ignition of an arc plasma in the vapors of the material of interest.

The originality of the method consists in the fact that the energy introduced into the system for ignition of the metal vapor plasma is supplied simultaneously by an electron gun and a high voltage source. Creation of the metal vapors is obtained by electron bombardment of the anode material with electrons emitted by the filament and accelerated between the electrodes.

2. Experimental setup

The experimental arrangement of the TVA technique consists in a grounded cathode containing a Tungsten filament surrounded by a Wehnelt cylinder and an anode, which is usually a crucible containing the solid material to be evaporated (bulk metal, carbon rod).

A schematic view of the experimental setup is presented in Fig. 1.

The basic principle of generation of the TVA plasma is presented in the following.

Electrons emitted by the filament are directed towards the anode by a Wehnelt cylinder. On application of a positive high voltage on the anode, the electrons are accelerated and produce heating of the anode material. Subsequently, the first vapors appear. A further increase of the applied voltage accelerates the electrons producing more vapors of the anode material. The first ions also appear as a result of fast-electron collisions with neutrals. At a certain value of the applied voltage, ignition of an arc plasma is obtained in the vapors of the anode material.

In Fig. 2, an image of a TVA plasma ignited in Cu vapors is shown as example. As can be observed in this figure, the TVA plasma is localized, it does not fill the chamber. This fact is also important, as the substrate can be protected against the thermal heat of the plasma by placing it away from the core of the plasma.

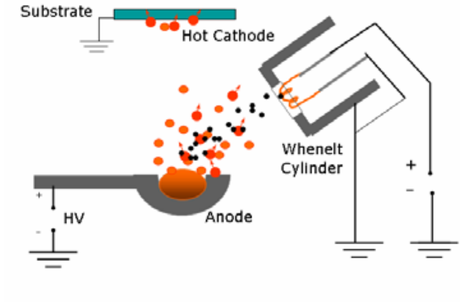

Fig. 1. Experimental set-up of TVA.

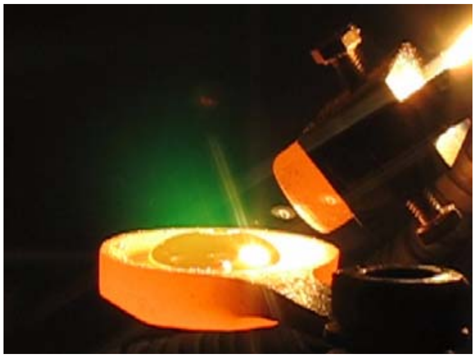

Fig. 2. A TVA plasma ignited in Copper vapors.

Nucleation is obtained by both ionic and neutral species formed in the plasma.

The ions created in the plasma are accelerated towards the chamber walls (and subsequently towards the substrate) due to the potential difference between the plasma and the grounded walls. Also, the neutrals diffuse out of the plasma due to the pressure gradient between the place they are created and the rest of the chamber which is vacuumed. Thus, the film is formed by both ions and neutrals.

As the transport of ions to the substrate is made without collisions, the ion energy is given by the potential difference between the plasma potential and the substrate potential which is usually grounded. This fact is an important asset of the technique, as the ion energy can be fully controlled by the operating plasma parameters.

In Fig. 3, a typical I-V characteristic showing the ignition stages of a TVA plasma at two different filament currents is presented. The plot shows that with increasing voltage, the arc current increases up to a point where a sudden voltage drop and a simultaneous increase of the arc current is observed. At this latter point, a stable arc plasma is ignited. Typical values of the operating parameters during TVA plasma ignition range between 500 to 2000 mA and 1000 to 1800 V for filament currents from about 50 to 70 A.

The filament current also influences the I-V characteristic of the TVA, as can be observed in this figure.

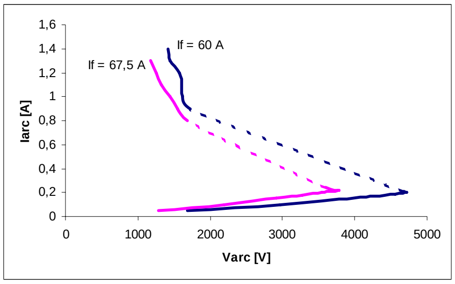

Fig. 3. Current voltage characteristic of the TVA plasma showing both the ignition stage and the stable operation.

As mentioned above, the ion energy is given by the plasma potential. Also the ion density is proportional to the power input.

In Fig. 4, the dependence of the plasma potential and power input on the arc current for different filament currents is shown. At higher arc currents, the ion energy decreases whereas the ion density increases.

The TVA deposition method provides neutrals and energetic ions of the material to be deposited. The ion energy and density can be fully controlled by the plasma operating parameters: arc current and voltage, filament current.

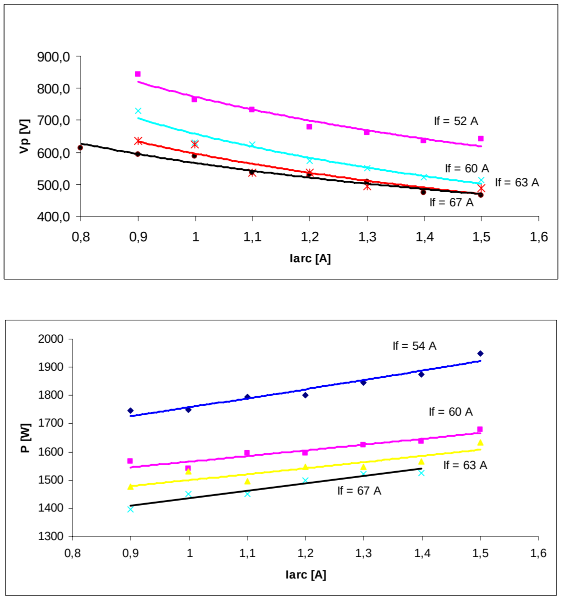

Fig. 4. The dependence of the plasma potential on the operating parameters a) and of the power input b) on the operating parameters (Ni plasma).

4. Discussion and conclusions

TVA is an anodic arc. In the case of Cathodic Arc, the vapors are created using high currents (hundreds of Amperes), whereas in the case of TVA, an external heating system with electrons is used which makes possible ignition of the plasma at low currents (hundreds of mA). The high currents used in Cathodic Arc trigger formation of clusters of materials which result in poor smoothness of the final surface, a special filtering being needed (Filtered Cathodic Arc). From this point of view, the TVA system is superior to the known arc plasmas.

Another important asset of the TVA is controllability of ion energy via plasma parameters.

The properties of thin films depend on growth conditions. The degree of independent control gives greater flexibility in controlling the structure, properties and deposition rate.

As shown above, the ion energy and density can be fully controlled by the plasma operating parameters. Due to the fact that the ion energy and density can be controlled in the TVA plasma and they also represent the main parameters influencing film characteristics, the TVA method has great potential to become an important thin film technology.

It should also be mentioned that no buffer gas or catalyst is needed, this ensuring the synthesis of high purity layers. As the system is placed in vacuum, no particles for heat conduction are present and therefore the substrate is only heated by the ions impinging on the surface. This makes the TVA method suitable for deposition on plastics and other low thermally resistant materials. Also, this low heat conduction minimizes the energy loss which makes the deposition method industrially competitive. Also, deposition temperatures as low as 100 °C are possible due to the localization of the arc plasma.

The films obtained using TVA plasma are very adherent, compact, smooth and pure.

This paper is meant to draw attention on an original deposition technique which has recently shown great potential for an extremely large range of applications.

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